THE DEVELOPMENT OF A TRANSIENT MAGNETIC FIELD MEASUREMENT TECHNIQUE FOR IMPEMENTATION ON A FUSELAGE-LIKE TEST SETUP

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Abstract

The susceptibility of airborne vehicles to electromagnetic (EM) transients has been studied for many years. In the case of lightning attachment, the current may flow along the surface of the conducting fuselage and disperse around the circumference. A portion of it can penetrate through the fuselage (by diffusion) resulting in transient EM fields on the inside that can result in EM interference to onboard electronics. In the laboratory, an aluminum test cylinder, representative in size and construction of a fighter-type aircraft fuselage, was subjected to high current pulses. An improved technique, the use of new two-dimensional magnetic flux density (B) probes is being developed to determine the magnitude of magnetic flux density outside and inside the cylinder as a result of transient currents flowing along the cylinder. The mating of these probes with a wide bandwidth fiber optic system for transient data acquisition and the overall system calibration procedures are presented.

Key Words: Lightning strike effects, aircraft fuselage, magnetic field distribution, surge current measurement, magnetic flux density measurement.

I. INTRODUCTION

During thunderstorms an aircraft might be hit by lightning. The lightning current may flow along the surface of the fuselage. A typical nose-to-tail lightning strike path is shown in Figure 1. In such a strike, most of the lightning current disperses around the circumference of the fuselage of the aircraft.

When the lightning current flows along the surface of the fuselage, a portion of it also penetrates inward and through the fuselage. Therefore, an electromagnetic (EM) field develops gradually in the interior of the fuselage. This process is called diffusion.

Understanding the build-up of the EM field inside the fuselage is important. The field build-up affects the electromagnetic compatibility (EMC) performance of the fuselage and sensitive equipment located in it [1, 2]

The main objective of this paper is to describe the technique and procedures for the measurement of the magnetic field distribution on a fuselage test setup. The technique is illustrated by a case study. It is the description of actual measurements related to the test setup.
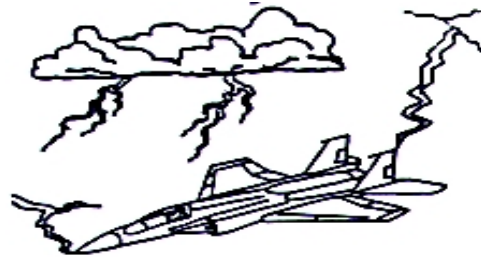

Figure 1. Nose-to-tail lightning strike.

II. MAIN TEST FACILITIES

The test facility for the study described in this paper is the mock airplane fuselage test setup at the Air Force Research Laboratory at Wright Patterson Air Force Base. The facility consists of a surge current generator, an aluminum test cylinder, data acquisition system, instruments, and a shielded room.

The circuit created by the lightning and the aircraft can be simplified and simulated in the laboratory. A cylinder represents an aircraft fuselage of simplified geometry.

The dimensions of the laboratory test cylinder (10 m long, 1 m in diameter) approximate the dimensions of the fuselage of a fighter-type aircraft. In the laboratory setup, a surge current generator (a large capacitor bank) provides a high current pulse, which is applied to the cylinder end adjacent to the capacitor bank through four energizing conductors. The current pulse flows along the cylinder surface, exiting at the other end of the cylinder.

1. REPORT DATE **JUN 2001**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**		
4. TITLE AND SUBTITLE **The Development Of A Transient Magnetic Field Measurement Technique For Impementation On A Fuselage-Like Test Setup**		5a. CONTRACT NUMBER		
		5b. GRANT NUMBER		
		5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S)		5d. PROJECT NUMBER		
		5e. TASK NUMBER		
		5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Dept. of Electrical Engineering, The Ohio State University, Columbus, Ohio 43210, U.S.A.**		8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)		
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)		

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. IEEE International Pulsed Power Conference (19th). Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License.

14. ABSTRACT
The susceptibility of airborne vehicles to electromagnetic (EM) transients has been studied for many years. In the case of lightning attachment, the current may flow along the surface of the conducting fuselage and disperse around the circumference. A portion of it can penetrate through the fuselage (by diffusion) resulting in transient EM fields on the inside that can result in EM interference to onboard electronics. In the laboratory, an aluminum test cylinder, representative in size and construction of a fighter-type aircraft fuselage, was subjected to high current pulses. An improved technique, the use of new two-dimensional magnetic flux density (B) probes is being developed to determine the magnitude of magnetic flux density outside and inside the cylinder as a result of transient currents flowing along the cylinder. The mating of these probes with a wide bandwidth fiber optic system for transient data acquisition and the overall system calibration procedures are presented.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT **SAR**	18. NUMBER OF PAGES **4**	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**			

The current pulse then returns to the capacitor bank over sixteen conductors, spaced coaxially around the cylinder.

This coaxial arrangement ensures that the total circuit inductance is kept as low as possible and that the current will be evenly distributed on the cylinder surface due to a pseudo-uniform EM field around the cylinder.

The sensor of the surge current is a calibrated device, and its frequency response is also known.

III. MAGNETIC FLUX DENSITY PROBES DEVELOPED

The magnetic flux density probes are small coils. They are positioned on or close to the surface of the fuselage, externally and internally.

A single-coil probe in a specific position and orientation can be used for the measurement of the magnetic flux density caused by a current. If that current is flowing axially along the cylinder, then the plane of the single coil should be oriented radially at any point for magnetic field distribution measurements. The "mean" loop of the probe is in that plane. That orientation ensures maximum coupling with the tangential component of the magnetic flux density vector caused by the currents flowing along the cylinder. The output of the coil is proportional to the time derivative of the current.

A new dual-coil probe has been designed (Figure 2), fabricated and tested for the measurement of such cylinder currents that have axial (i.e., flowing along the cylinder) and tangential (or circumferential) components. The two orthogonal coils are in two slots of a small (28 mm) cube, and they can measure the axial and tangential components of the magnetic flux density simultaneously. The synthane body (i.e., the small cube) of the dual-coil probe is shown on the left side of Figure 2. The right side of Figure 2 shows the probe complete with coils and terminals.
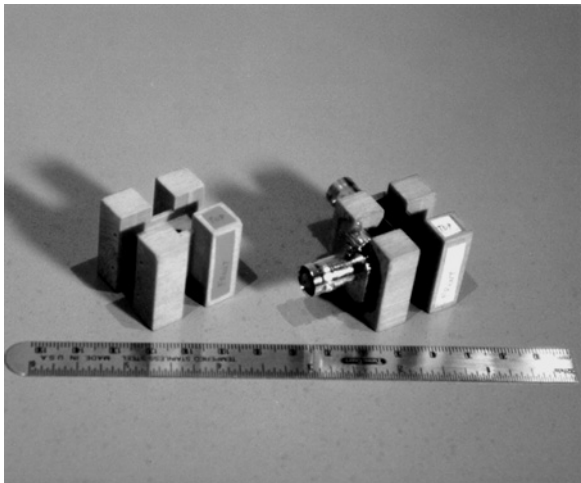

Figure 2. Dual-coil probe design.

Each coil consists of 17 turns of 22 AWG enamel coated magnet wire. Electric field shields are placed on both the inner and outer surfaces of each coil. Each shield has a gap located directly opposite the BNC connector for that coil.

The use of the dual-coil probe is essential for the measurement of current distribution around apertures (windows), or at areas where the current flow is not axial (e.g., joints of the fuselage and wings).

A third coil is not necessary since the radial current component at any point is very small.

IV. CALIBRATION OF THE MEASUREMENT SYSTEM

The following steps were necessary for the calibration of the magnetic flux density measurement system:

A. Probes and Other System Components

First, the complex impedance of the probe coils vs. frequency was measured. A typical frequency range is 5 kHz - 0.5 MHz. No resonance occurred in that frequency range. A network analyzer was used for such tests. Figure 3 shows the impedance of a probe coil as a function of frequency. The lower (continuous) line is the magnitude of the impedance in ohms, its scale factor is 2 ohms/div., its zero line is the bottom line of Figure 3. The upper (dashed) line is the phase angle in degrees, its scale factor is 45 deg/div., its zero line is the center line of Figure 3.
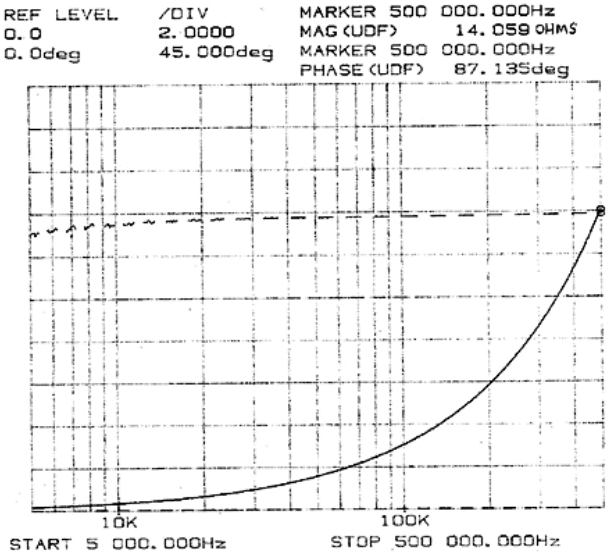

Figure 3. Probe impedance.

The next test of the probe coils was to insert them into a known magnetic field (e.g., the magnetic field of a large solenoid), and determine the probe output vs. magnetic flux density function for the frequency range indicated

above. Figure 4 shows the calibration factor of a probe coil as a function of frequency. The lower line is the magnitude of the factor in mV/microgauss, its scale factor is 50 E-6 mV/microgauss/div., its zero line is the bottom line of Figure 4. The upper line is the phase angle in degrees, its scale factor is 45 degrees/div., its zero line is the center line of Figure 4.
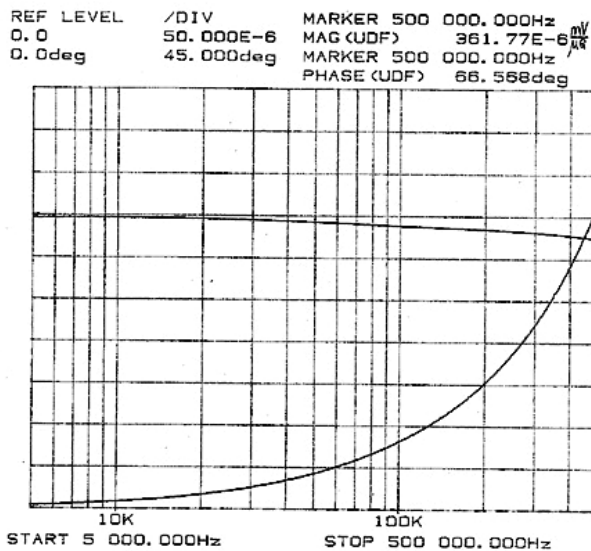

Figure 4. Probe calibration factor.

The response of the magnetic flux density probes was checked at known currents. If two different types of probes are calibrated simultaneously, their responses at the same current can be compared easily. The probe performance was verified for various periodic waveforms, and for transient currents as well.

Appropriate filtering was necessary to remove the high frequency noise from the probe output.

Then, the response of the fiber optic link (transmitter, cable, receiver) between each probe and the scope was checked at various frequencies and signal magnitudes.

The characteristics of the scope, attenuators and amplifiers, e.g., attenuations and gains as a function of frequency, were also checked.

Electric field shielding of the coils is necessary in order to reduce the noise level during measurements.

The probe output was negligible when the probe was exposed to any electric field. Figure 5 shows the test setup when the probe was exposed only to a transient electric field of about 6 kV/cm magnitude, using the surge generator of the High Voltage Laboratory of The Ohio State University (OSU), and an appropriate electrode arrangement.

B. Entire System

The frequency response of the entire interconnected instrumentation system (i.e., the probe, fiber optic

transmitter, cable and receiver, attenuators, amplifiers, filters, scope) was also determined.

Figure 6 shows the system test of one of the dual-coil probe coils. The upper trace shows a transient current of 16.67 A peak value at 2.5 microsecond time-to-peak. This is a small current through the voltage divider of the surge voltage generator at OSU. The lower trace shows the probe coil output, to be multiplied by (-1).

Since the probe output is proportional to the derivative of the magnetic flux density produced by the current, the largest output value of the probes occurs when the derivative of the current change is the largest. Also, at the time of the peak value of the current, the probe output is zero. This derivative characteristic of the probe is incorporated in the calibration curve of Figure 4.

Waveforms of the fiber optic system input and system output were practically identical, and almost noise-free, at their level of optimal magnitude.
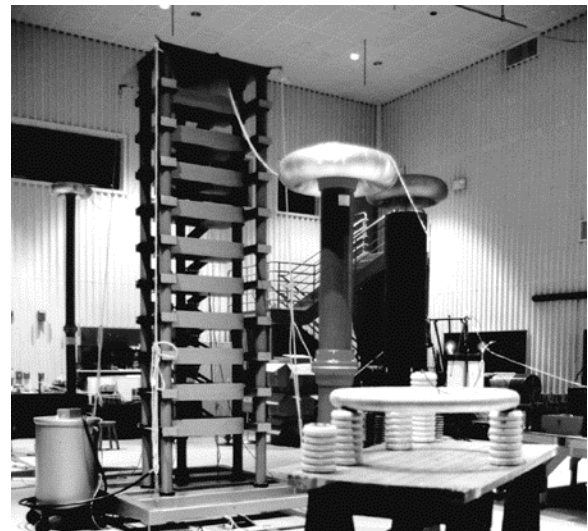

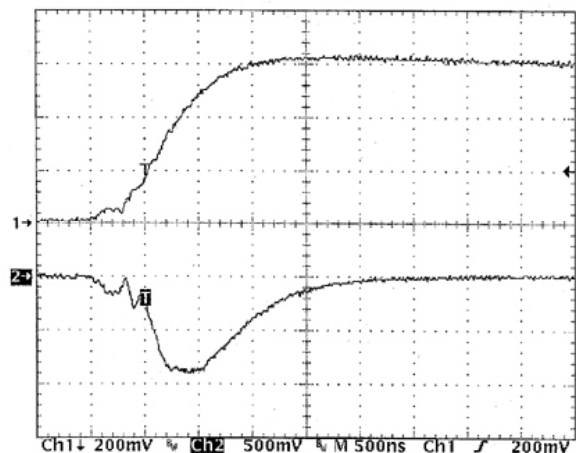**Figure 5.** Test setup for transient electric field exposure.

Figure 6. Response of the entire system.

V. DESCRIPTION OF THE MAGNETIC FIELD MEASUREMENT TECHNIQUE

The guidelines below have been followed during the measurement of the magnetic field distribution around and inside the test cylinder representing the fuselage of an aircraft:

The test cylinder was essentially closed, i.e., no end or window panels were removed.

The surge current magnitude and waveform were known.

Halfway along the test cylinder from the current injection end, the surge current distribution around the cylinder was assumed axial and uniform.

Magnetic flux density probes have been used initially at this midway area to determine the tangential magnetic flux density at test points outside and inside the test cylinder. The dual-coil probes will be used later at other cylinder sections, or around open window sections, etc., to determine the magnetic field distribution in various cases.

The dual-coil probes positioned outside the test cylinder measure two components of the outer magnetic flux density vs. time. The dual-coil probes positioned inside the test cylinder measure the two components of the inner magnetic flux density vs. time. As mentioned above, the integral of the probe output is proportional to the surface current.

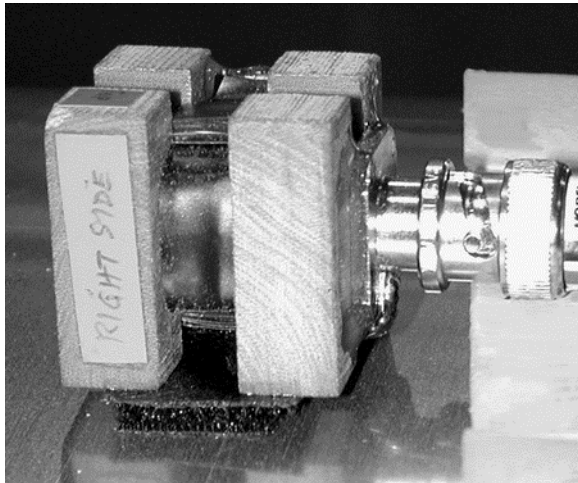Figure 7 shows one of the dual-coil probes attached to the test cylinder.

Figure 7. Dual-coil probe attached to the test cylinder.

A correction factor (CF) might be necessary due to the cylindrical geometry of the test facility. This correction factor is the ratio of the inside magnetic flux density to the outside magnetic flux density at the test points where the magnetic flux density probes are to be positioned.

For uniform steady state current distributions, if the diameter of the hollow cylinder is very large (i.e., when it can be represented by a flat plate) the tangential magnetic flux density values are the same at the inside and outside test points. Therefore, CF=1 for uniform steady state current distributions. This correction factor for the 1 m diameter aluminum test cylinder, if the test points are 45 mm from the surface of the cylinder, is CF=1.15, also for uniform steady state current distributions. The value of CF is approaching 1 when the test points are getting closer and closer to the surface of the cylinder, i.e., when the size of the probe is small.

Finally, the appropriate calibration factors will be applied in order to determine the actual magnitude of the measured quantities. That involves the use of time domain and frequency domain quantities.

VI. SUMMARY

The development (design, construction and testing) of a new custom-made dual-coil system has been successful.

Procedures related to the calibration of magnetic flux density probes, other system components, current measuring devices, and the entire interconnected measurement system have been developed.

The calibration measurements and procedures introduced make the transient current and magnetic flux density measurements possible and reliable.

VII. ACKNOWLEDGMENTS

VIII. REFERENCES

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[2] G. Tsai Li, S. A. Sebo, D. L. Schweickart, L. C. Walko, J. C. Horwath, R. Spyker, G. Webb, "Lightning Current Induced Magnetic Field Distribution Measurement Technique on a Mock Airplane Fuselage Test Setup," *Proceedings of the 11th International Symposium on High Voltage Engineering (ISH'99),* London, England, August 1999, Vol. 1, pp. 1.254-1.257.